IR Breakout Discussion Recap

- The discussion started (again) with a discussion of what are the science requirements (questions) and what are the instrument requirements. Part of this is due to the ambiguity between the ES and Chapter 9. Part is due to the fact that the ES only defines the instrument requirements.
  - Earlier presentations discuss the tight and integral relationship between the science and instrument requirements without fully describing what the instrument requirements are.
  - We agreed that it the mission is more simple if it is primarily a climate benchmark, with contributions to constraining the physics of models with cross correlation with operational sounders a secondary function.
  - There was much discussion (with an understanding that people will maintain differing opinions) about using the sounders as part of the past and future climate record (in coordination with CLARREO); is this a proper primary emphasis?
- There was also discussion as to the requirement of precision, to go along with the absolute accuracy as defined in the ES and the day one discussion.
- All agree that extending to the far infrared is an important and essential feature of the IR component of CLARREO.

NRC Societal Objectives

Provide a climate benchmark time series for use by future generations

Test climate models according to their predictive fidelity on decadal timescales

Scientific Requirements

Obtain accurate (SI traceable) mean annual climate state: atmospheric radiative state determined by temperature, water vapor, clouds, surface emission[1]

Constrain transient climate sensitivity through measurements of radiative forcing and climate response

Obtain SI technically feasible SI traceable measurements that document atmospheric variables: spectral longwave, microwave refractivity, spectral shortwave

Constrain longwave, shortwave feedbacks

High-level Requirements

Total uncertainty: 0.1 K in annual means at 15°x30° (2-σ)

Measurement accuracy[5,6,7] : 0.1 K (3-σ)

Measurement precision: 0.01 K after averaging

Semidiurnal bias: 0.05 K based on orbital constellation

Spectral resolution: 1 cm^{-1}

Spectral coverage: 200-3000 cm^{-1}

On-orbit SI traceability[7,8]

Temporal resolution: <60 sec intervals (benchmark)
<15 sec intervals (intercalibration)

Spatial/angular coverage: nadir only, <100 km footprint

Experimental Methods

Sample diurnal and semidiurnal variability[9]

Directly verify measurement accuracy on-orbit with third calibration point (blackbody): step 1 of SI traceability

Test for systematic errors on-orbit: all sources, blackbodies and otherwise: step 2 of SI traceability

Detector selection[10,11]

Spectrometer selection[12]

Accurate calibration standards[13,14]

NIST participation

Hardware Requirements

On-orbit thermometry calibration against international standards

On-orbit blackbody emissivity measurement

On-orbit polarization test

On-orbit characterization of Instrument Line Shape

Minimization and verification of detector signal chain nonlinearity

Attain adequate stray light rejection

Test flight sensor against NIST standards

Multiple spacecraft in true polar orbit

Results of Hardware Trade Studies†

Phase transition cell (gallium melt, *et al.*)

Radiation source(s) to illuminate blackbody cavity

View 45° swath of deep space

Fourier Transform Spectrometer (FTS)

On-board monochromatic, uniform source

2 blackbodies+deep space for calibration; multiple interferometers

Room-temperature pyroelectric detectors plus cooled detectors (MCT, potentially with InSb sandwich configuration)

Gravity gradient stabilized, fixed solar array spacecraft

†Trade study bibliography detailed in Technical Readiness Level section.

IR Breakout specifics…

- To fully address the diurnal and semi-diurnal cycle, 3 polar orbits are ideal.
  - Only using two would be useful, but begins to degrades the statistics of separating natural variability from trends.
  - Only one would not achieve this.
  - Multiple sun sync orbits give useful, but non-ideal sampling of the diurnal cycle.
- Why do we stop at 200 or 2400 cm-1?
  - Without seeing any optimal fingerprinting studies beyond these defined limits, it's unclear why they are set as instrument drivers.
  - Most think that getting the 100 to 200 cm-1 range is critical for understanding the climate feedbacks in the UT.
- There was not much need for discussion of a 1 cm OPD as most agreed it's probably in the right ballpark.
- We had a hard time knowing whether a 100 km, or a smaller footprint is ideal. This deserves much more study by the community.

- Primary data product from spectrometer
  - Annual mean brightness radiance T @15 degree grid of 0.1 K
  - Sufficient spectral information to identify causes of changes in brightness temperature (techniques LIKE optimal fingerprinting).
  - Minimum 5 year data record.
- Secondary product from spectrometer
  - Intercalibration of operational sounders
  - Weather people would like temperatures at this accuracy as well.
- Open Issues
  - nEdT needs to be sufficient to characterize on orbit systematic errors, tighter than required to meet CLIMATE science goals.
  - Future discussion/studies are required to determine this requirement.
- Spectral range
  - 200 to 2000 is a nominal starting point (in ES), needs to be refined based on optimal results from optimal fingerprinting.
  - 100-3300 in chapter 9
- 100 km FOV
  - Sufficient for annual gridded means
  - Some discussion as to whether this is sufficient for intercalibration with operational sounders, or even aircraft comparisons.
- Instrument type? Most agreed that an FTS is a robust way to do these measurements, but other types of spectrometers may meet the requirements as well.

- How does one validate an instrument that is designed to BE the benchmark?
  - Most existing instruments are not designed to have that absolute accuracy along with traceability since this is supposed to be a new paradigm.
  - Because CLARREO is a climate monitoring instrument, where statistics are required more than high precision and small footprint of an instrument that is primarily a sounder, numerous intercomparisons with an aircraft are required for a proof of the delivered data product. Can this really be done? Should it be done?
  - How does one fully understand the instrument characteristics in flight with an instrument where absolute accuracy drives the design much more so than precision (as driven by the science questions/cost/etc.).
  - Is the second tunable blackbody good enough verification of the absolute calibration on orbit? What happens if radiances from this second blackbody don't agree with the first in flight?

Costs?

- Spacecraft costs are a serious impediment to meeting the $200M mission cost.
    - Options exist that may decrease the costs, but are not yet NASA qualified.
    - If launch costs are not part of the equation (or at least a small part), then one could build the desired number of spectrometers. This is not the current metric.
- If current spacecraft costs are required, staying within the budget is not possible. Costing matrix studies were not presented.
- We did not get to potential international collaborations. This avenue needs pursuit.